# Correcting a mistake in the alignment procedure unveiled by the CSA07 alignment exercise

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8 November, 2007

## The story in brief

- I have been presenting alignment results for some time now
- CSA07 was supposed to be inconsequentially different (details next slide)
- We did not reproduce old alignment in CSA: 100 microns resolution $\rightarrow$ 1 mm!
- Extensive diagnostics ensued...
- Conclusion: the old alignment procedure is at fault, previous results were too optimistic
- We corrected our procedure and are now re-optimizing it
- Old questions must be reopened, systematics studies repeated

# Differences between CSA07 and previous studies

- Miscalibrated hits

  Miscalibration effect studied in isolation: too small to account for differences

- CMSSW version 1_6_4 instead of 1_5_4

  Reconstructed and aligned one sample in all 4 combinations of releases: no errors

- Tracks fit with misalignments

  Reconstructed with and without misalignments at each stage of reconstruction: the problem is in track-fitting with misalignments

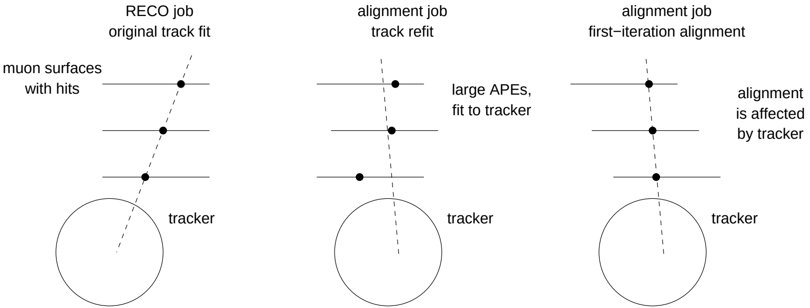
## Background: misalignments in alignment simulations

- In the detector simulation: defines the "true" geometry, the objective of alignment, in the same way as data. Not yet possible in CMSSW.
- In track reconstruction: weak effect on the choice of hits associated with tracks (roads are wide compared to misalignments), strong effect on the fitted track, but we refit the track in alignment
- In the alignment process: strong effect on the refitted tracks in the first iteration

We have always misaligned in the alignment process; in CSA07, we also misaligned the initial track reconstruction (RECO job)

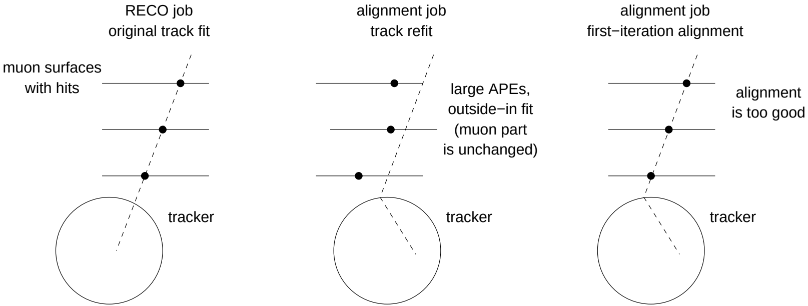
Lost $\sim$0.5 hits per track due to RECO misalignment: cannot account for $10\times$ degradation in alignment!

# How globalMuon alignment is *supposed* to work




Geometry used in RECO is irrelevant because tracks are refit.
Muon hits are deweighted with large Alignment Parameter Errors (APEs) to effectively fit to tracker and extrapolate to muon system

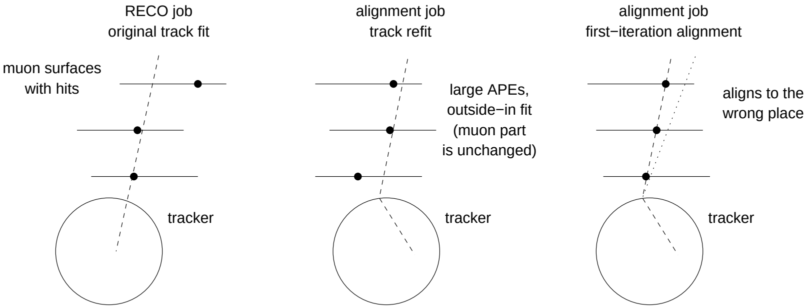
# Mistake in the old procedure: outside-in fits




Ideal RECO geometry creates ideally-fitted tracks. Refitting starts from the outside and works inward, *causing minimal changes to track parameters* because of the large APEs.

Alignment output was too good because information about the ideal geometry was encoded in the unchanged part of the track

# How we found it with CSA07




CSA07 event samples are misaligned at the RECO level, so we get a non-ideal track seed. The muon part of the track is again not changed, so we incorrectly align to whatever was used in RECO.

Hence, difference from ideal is large.

## Lessons

1. In a globalMuon alignment (extrapolating from tracker to muon system), always use an inside-out fit!
2. In a standAloneMuon alignment, don't make APEs too large!
3. Corrected simulation results $\approx$ muon alignment scenarios

## What to do about it

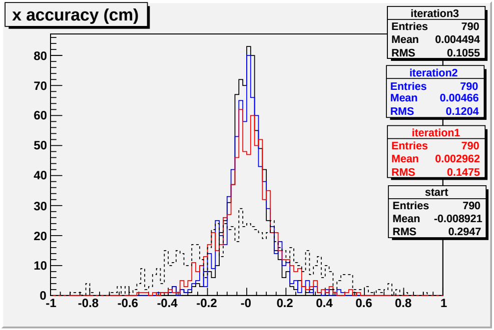
(blue is new, black is an update)

- Optimize a new procedure using inside-out fits
- Choose a $p_T$ cut in a generic sample (revisit low momentum now that we need statistics)
- CSA with 10 and 100 $\mathrm{pb}^{-1}$: make baseline alignment scenarios
- Systematics studies: tracker misalignment, miscalibration, material/$\vec{B}(\vec{x})$ dependence
- Study performance in standAlone muon $Z$, globalMuon $Z'$/Drell-Yan

# Optimizing a new alignment procedure

# Alignment with inside-out fits

100k events (25 $pb^{-1}$), 8 mm APEs, 3 iterations




| | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Muon barrel stations | 490 $\mu$m | 680 $\mu$m | 960 $\mu$m | 1.4 mm |
| Muon endcap ME$x$/1 stations | 510 $\mu$m | 670 $\mu$m | 980 $\mu$m | 1.1 mm |
| Muon endcap ME$x$/2 stations | 830 $\mu$m | 1.2 mm | 1.5 mm | |

## Problem: scattering in material is cumulative

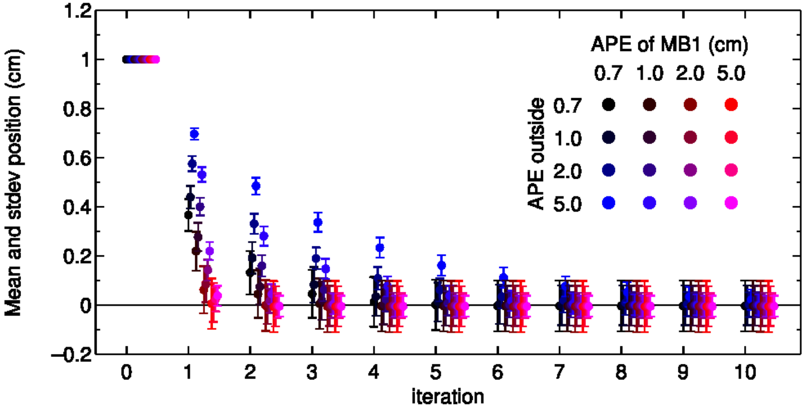
## Solution: minimize extrapolation by aligning in stages

1. Align station 1 only with loose APEs
2. Align station 2 with tight APEs on 1, loose on the rest
3. ...

Test-scenarios (local $x$ only, 10 $\text{pb}^{-1}$)

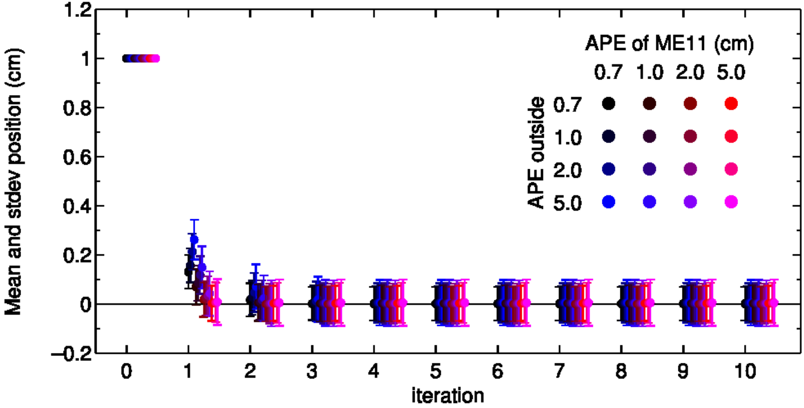
- 3 mm Gaussian misalignment for unaligned chambers
- 1 cm coherent misalignment for chambers under study
- $\sqrt{N} \times 500$ $\mu$m Gaussian residual misalignment for aligned chambers ($N$ is the station number)
- Vary "loose" APEs on chambers under study 0.7–5 cm
- Vary "loose" APEs on outer chambers 0.7–5 cm

# Innermost barrel station (MB1)



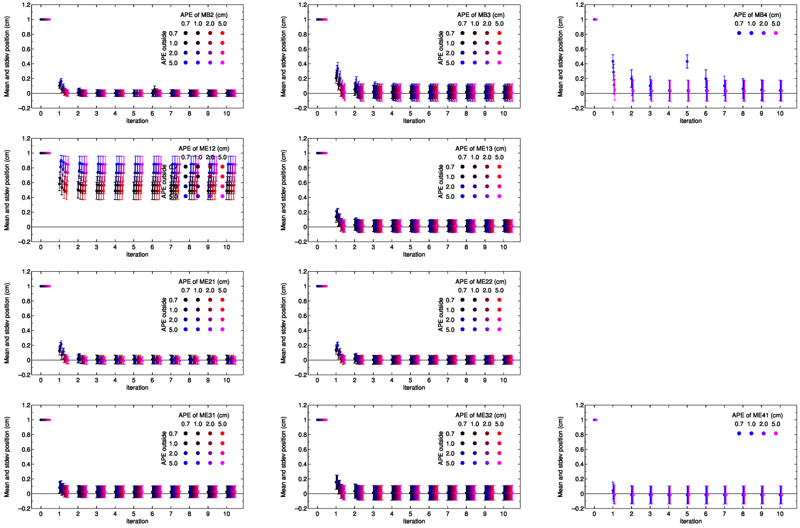

- Large APE on MB1 improves convergence of mean (accuracy)
- Large APE on MB2, MB3, MB4 reduces stdev (precision)
- Dropping MB2, MB3, MB4 from fit (infinite APE) is worse

# Innermost endcap station (ME1/1)

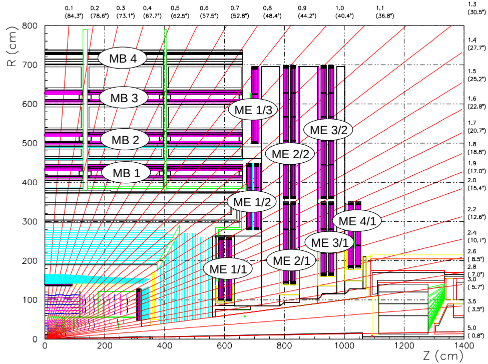



- All cases converge quickly
- All stdevs are large (680 $\mu$m)

# All the rest (discussion on next slide)



- ME1/2 did not converge! Loosen APEs: 5, 7, 10, 15 cm
- Why ME1/2? What's special about it? The solenoid?




- Only in MB1 do we see a range of convergence speeds (parameters were chosen using MB1 as a test-case)
- For the rest (excluding ME1/2), tighten APEs to get more precision at the expense of convergence: 0.05, 0.1, 0.2, 0.5 cm

## Current status

- Station-by-station results are about a factor of 2 better than all-at-once method (taking $\sqrt{25\ \mathrm{pb}^{-1}/10\ \mathrm{pb}^{-1}}$ into account)
- But they still show a strong dependence on cumulative propagation (either material or cumulative error)

| | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Muon barrel stations | 420 $\mu$m | 440 $\mu$m | 850 $\mu$m | 1.5 mm |
| Muon endcap ME$x$/1 stations | 680 $\mu$m | 490 $\mu$m | 822 $\mu$m | 1.2 mm |
| Muon endcap ME$x$/2 stations | 770 $\mu$m | 520 $\mu$m | 1.0 mm | |

- Standard 10 $\mathrm{pb}^{-1}$ scenario has 500 $\mu$m misalignments
- Relative alignments are much more precise: if we had no uncertainty in MB1, MB2 would have 70 $\mu$m resolution; worst *relative* case is 270 $\mu$m (ME1/1 $\rightarrow$ ME2/1)

# Next steps

1. Optimize globalMuon and/or standAlone muon procedure
2. Scale best case up to 100 $\mathrm{pb}^{-1}$
3. Do a full alignment exercise with $Z \rightarrow \mu\mu$ (CSA07-1)
4. Apply alignment results to physics ($Z$, $Z'$, Drell-Yan)
5. Explore low-momentum muons ($Z$+$W$+QCD-mu: CSA07-2)
6. Re-do systematics studies, including material $\rho(\vec{x})$ and $\vec{B}(\vec{x})$ (which I now know how to do)